6G-Reconfigurable Intelligent Surface Channel Estimation and Phase Optimization

Members ：吳乙萱、陳家齊 Group：B337 Advisor：劉光浩教授

Abstract

In wireless networks, a major challenge is the coverage dead zone problem where signal strength is too weak to meet the communication requirement. The Reconfigurable Intelligent Surface (RIS) serves as a solution of coverage dead zones by reflecting radio signals to the desired direction. This is achieved by controlling the phase shifts of RIS elements that forms passive beamforming.

This project aims to optimize the active beamforming vector at Access Points (APs) and the passive beamforming vector of the RIS so as to consume the least power for meeting the communication quality requirement. Since the design of both active and passive beamforming vectors requires the channel state information (CSI), we consider a practical channel estimation method using a finite number of pilot symbols. Simulation is performed to investigate the impact of various factors, including the number of pilot symbols, the number of RIS elements, and the number of AP antennas to the required transmission power at the AP.

Method

We iteratively compute the active beamforming vector and RIS phase shift as follow.

1. **Beamforming vector (w)**

$$\omega^* = \frac{\sqrt{P}\left(\mathrm{h}_r^H \Theta \mathrm{G} + \mathrm{h}_d^H\right)^H}{\left\|\mathrm{h}_r^H \Theta \mathrm{G} + \mathrm{h}_d^H\right\|}$$

Given fixed RIS phase shifts, the beamforming vector at the AP is determined following the maximum ratio transmission (MRT) principle that can maximize the signal-to-noise ratio (SNR).

2. **Phase shift (θ)**

$$\theta_n^* = \varphi_0 - \arg\left(h_{n,r}^H \boldsymbol{g}_n^H \overline{\boldsymbol{\omega}}\right) = \varphi_0 - \arg\left(h_{n,r}^H\right) - \arg\left(\boldsymbol{g}_n^H \overline{\boldsymbol{\omega}}\right),$$

The transmitted signal suffers the phase rotation due to the wireless fading channel. RIS can be viewed as a phase compensator that eliminates the phase offset by adjusting the phase shifts of RIS elements.

3. **Transmit power (P)**

$$\mathrm{P} = \frac{\gamma\sigma^2}{\left\|\mathbf{h}_r^H \boldsymbol{\Theta} \mathbf{G} + \mathbf{h}_d^H\right\|^2}$$

By iteratively optimizing **w** and **θ**, we are able to minimize the transmit power given above.

Reference

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2. 2. Y. S. Cho and et al., MIMO-OFDM Wireless Communications with MATLAB, John Wiley & Sons (Asia) Pte Ltd, 2010
3. 3. X. Wei, D. Shen, and L. Dai, “Channel estimation for RIS assisted wireless communications: Part II - an improved method based on double-structured sparsity,” IEEE Communication Letters., vol. 25, no. 5, pp. 1403-1407, May 2021
4. 4. Q. Wu and R. Zhang, "Intelligent reflecting surface enhanced wireless network via joint active and passive beamforming," IEEE Transactions on Wireless Communications, vol. 18, no. 11, pp. 5394-5409, 2019

Result

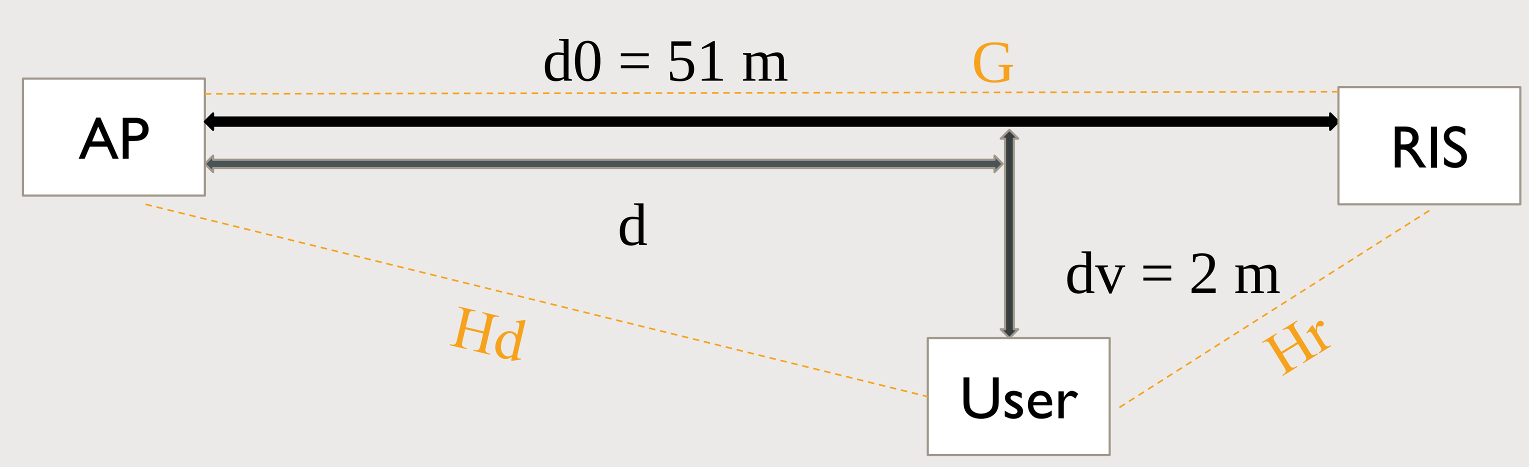

Fig. 1. Simulation setup of the signal-user case (top view).

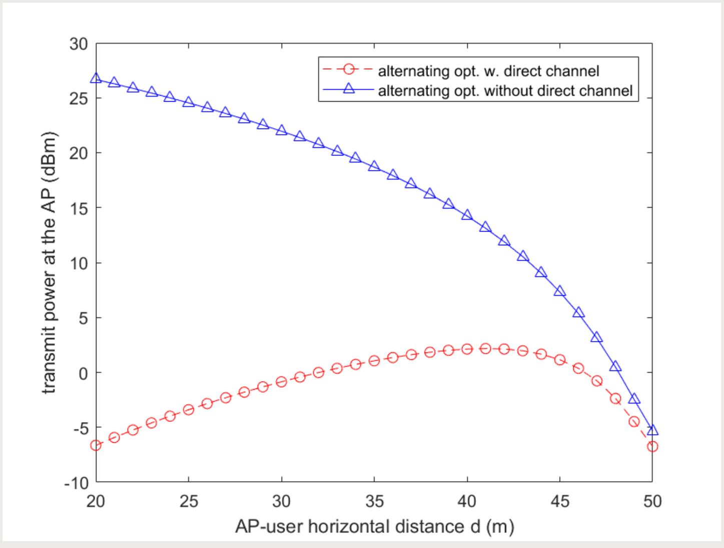

Fig. 2. Transmit power with and without direct channel.

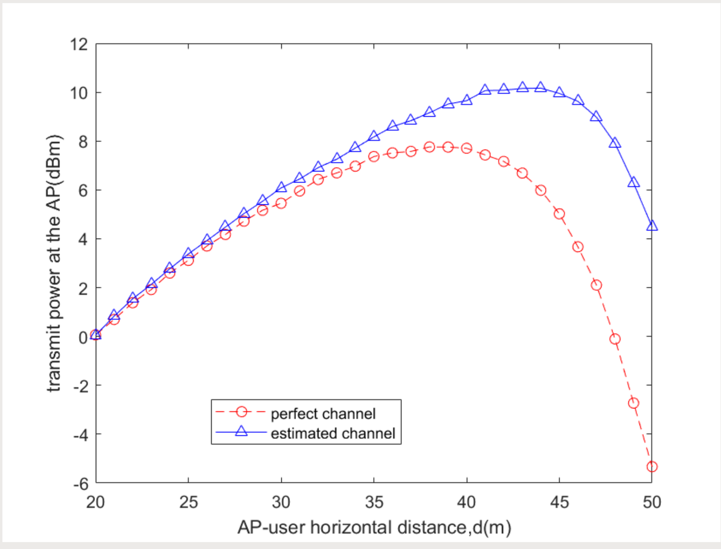

Fig. 3. Transmit power of perfect and estimated channel.

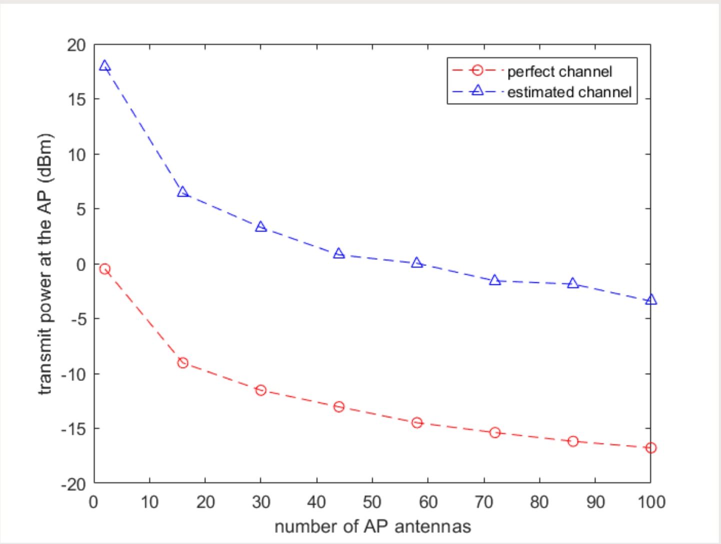

Fig. 4. Impact of channel estimation error to the transmit power under different number of AP antennas.

From Fig. 2., it can be observed that the transmission power of the scenario with a direct channel is lower than that without a direct channel. This is because the presence of a direct channel and RIS reflection introduces two paths. As a result, the AP can use less power to satisfy the communication requirement compared to the case without a direct channel.

From Fig. 3., we see that
1) Channel estimation errors cause a higher power consumption at the AP.
2) The transmit power first increases with the distance *d* and then decreases. This is because when the user is further away from the AP, the direct channel becomes weaker that costs more transmit power to meet the communication requirement. Meanwhile, the user benefits more from the RIS reflection when it is closer to the RIS that helps to reduce the transmit power at the AP.

From Fig.4, the required transmit power is reduced by increasing the number of AP antennas. However, the additional power consumption due to channel estimation errors can not be mitigated by adding more AP antennas.